The Dual Dust Chemistry - Binarity Connection

Orsola De Marco

American Museum of Natural Histroy, Central Park West at 79th Street, New York, NY 10024

A.F. Jones

Carter Observatory, New Zealand

M.J. Barlow

University College London, UK

M. Cohen

University of California at Berkeley, USA

H.E. Bond

Space Telescope Science Institute, USA

D. Harmer

National Optical Astronomy Observatories, USA

Abstract. Accumulating evidence points to a binary nature for the Wolf-Rayet ([WC]) central stars, a group that constitutes about 15% of all central stars of planetary nebula. From ISO observations, a dual dust chemistry (oxygen- and carbon-rich) has been shown to be almost exclusively associated with [WC] central stars, a fact that could be explained by O-rich dust residing in a disk, while the C-rich dust being more widely distributes. HST/STIS space resolved spectroscopy of the [WC10] central star CPD–56º8032, is interpreted as revealing a dust disk or torus around the central star. This, together with CPD–56º8032's variable lightcurve is taken as an indirect indication of binarity. Finally, we present here, for the first time, preliminary results from a radial velocity survey of central stars. Out of 18 stars with excellent data at least 8 are radial velocity variables. If these turn out to be binaries, it is likely that the central star binary fraction is as high as ∼50%.

1. Prologue

WC Wolf-Rayet central stars of planetary nebulae ([WC] central stars of PNe) are H-deficient stars that exhibit strong ionic emission lines of helium, carbon

and oxygen from their dense stellar winds. Amongst the coolest central stars in this group are CPD–56º8032 (the nucleus of the PN He 3-1333) and the central star of He 2-113 (both classified as [WC10], Crowther et al. 1998). Cohen et al. (1986) found the mid-infrared KAO spectra of both these objects to show very strong unidentified infrared bands (UIBs – usually attributed to polycyclic aromatic hydrocarbons, PAHs). Indeed, both the nebular C/O ratios (De Marco, Barlow & Storey 1997) and the ratio of UIB luminosity to total IR dust luminosity (Cohen et al. 1989) for these two objects are the largest known. It was therefore a major surprise when mid- and far-IR Infrared Space Observatory spectra of these two objects showed the presence of many emission features longwards of 20 μm that could be attributed to crystalline silicate and water ice particles (Barlow 1997, Waters et al. 1998a, Cohen et al. 1999), indicating a dual dust chemistry, i.e. the simultaneous presence of both C-rich dust and O-rich dust. The dual dust chemistry phenomenon in PNe appears to show a strong correlation with the presence of a late WC ([WCL]) nucleus – four out of six [WC8-11] nuclei studied by Cohen et al. (2002) showed similar dual dust chemistries. In the context of a single star scenario, this would point to a recent transition (within the last $\sim$1000 yr) between the O- and the C-rich surface chemistries. However, the probability of finding a post-AGB object that had recently changed from an O-rich to a C-rich surface chemistry due to a third dredge-up event should be very low indeed. An alternative scenario envisages these systems as binaries (Waters et al. 1998a, Cohen et al. 1999, 2002), in which the O-rich silicates are trapped in a disk as a result of a past mass transfer event, with the C-rich particles being more widely distributed in the nebula as a result of recent ejections of C-rich material by the nucleus.

2.   A Dusty Disk around CPD–56º8032

CPD–56º8032 exhibits a variable optical lightcurve (Pollacco et al. 1992, Jones et al. 1999), with minima which are $\sim$1 mag deep and have a 5-year pseudo-period (Cohen et al. 2002). This was interpreted by Cohen et al. as precession of a dusty disk. We present an updated light-curve for CPD–56º8032 in Fig. 1.

De Marco et al. (2002) presented HST/STIS spatially-resolved spectroscopy of CPD–56º8032, obtained during its third visual light minimum, which revealed the stellar near UV and blue optical continuum to be split into two spectra separated by about 0.10 arcsec. Once other possibilities were excluded (e.g., instrumental problems or the presence of two stars), the simpler explanation is that CPD–56º8032's light is seen reflected by the upper and lower rim of a dusty disk or torus seen close to edge-on. If so, CPD–56º8032 could be similar to the Red Rectangle (HD44179; Osterbart et al. 1997), whose binary central star light is seen indirectly, reflected by the rims of an edge-on disk. In this binary scenario, CPD–56º8032's light-curve could also be interpreted as CPD–56º8032's orbital motion taking it in and out of alignment with a denser part of the disk, such that its brightness is modulated in step with the binary period. An alternative scenario that is more in line with the asymmetric lightcurve declines, conceives a dust clump in orbit with the disk passing in front of CPD–56º8032 every 5 years. The companion cannot be bright enough to contaminate substantially its spectrum, which is reasonably fit with a single Wolf-Rayet model atmosphere (De
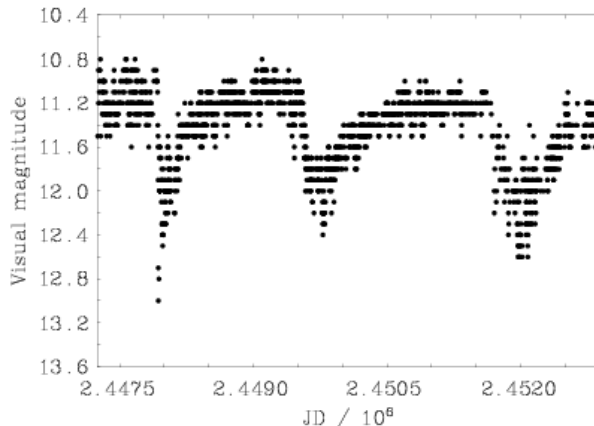
Figure 1.   The visual lightcurve of CPD–56º8032 between March 1988 and September 2003.

Marco & Crowther 1998). CPD–56º8032's putative companion could plausibly be a low mass main sequence star, such as a K dwarf.

Interestingly, the Red Rectangle, also a binary, is the only system to have a double dust chemistry and a central star which is *not* hydrogen-deficient. From this we could suggest that the Red Rectangle's A supergiant central star (the other is thought to be an unseen white dwarf [Men'shchikov et al. 2002]) might be on its way to becoming hydrogen deficient.

The conjecture that [WC] stars are binary systems is in harmony with the fact that binarity is generally known to promote mass-loss. For instance, all the massive Wolf-Rayet stars in the metal-poor Small Magellanic Cloud are binaries. This has been explained with the fact that the low metallicity of the SMC leaves its stars with atmospheres with relatively low opacities, too low to develop the dense Wolf-Rayet winds. Hence the only massive Wolf-Rayet stars possible in the SMC are those where a companion has facilitated mass-loss.

A direct detection of binarity via radial velocity monitoring (see Section 3), is unlikely in the case of [WC] central stars, because of their intrinsically variable (e.g. Balick et al. 1996), broad emission lines.

3.   Preliminary Results of a Central Star Radial Velocity Survey

There are increasing indications that binary-star processes are intimately related to the ejection of many, or possibly even most, PNe. The evidence includes: the fact that $\sim$10% of PN nuclei are found to be very close binaries (periods of hours to a few days; Bond & Livio 1990, Bond 2000) through photometric monitoring; population-synthesis studies suggesting that these may be just the short-period tail of a much larger binary population extending up to orbital periods of several months (Yungelson et al. 1993, Han et al. 1995); and the prevalence of highly non-spherical morphologies among PNe.

The photometric search technique does not work for binaries with periods of more than a few days, since it relies on proximity effects. We have therefore

carried out radial-velocity monitoring of a sample of PN nuclei, in order to search for the anticipated population of binaries with periods up to a few months. If they do exist, there will be new implications for the evolution of binary populations, the origin of compact binaries (CVs, SN Ia progenitors), and even the question of whether single stars can produce visible ionized PNe at all.

This program was started in May 2002 at the 3.5-m WIYN telescope. Despite being plagued by very bad weather and some instrument problems, we report that 8 of the 18 central stars for which we have more than five data points have *clear* radial velocity variability. The independent, but similar program of Pollacco et al. (these proceedings) returned a similar radial velocity variable central star fraction. However, it will take additional observations for us to have robust statistics, and to determine orbital periods needed to show conclusively that the velocity variations are due to binary motion and not, for instance, to wind variability.

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